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Coin Attribute

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Specific Gravity: A Useful Coin Attribute

Appearing with increasing frequency in numismatics the terms density and specific gravity, understood by many collectors, are yet cloudy to others. To some the words are complete strangers. The aim of this article is to give insight into the concepts, to detail the method for their determination and to illustrate useful numismatic applications.

INTRODUCTION:-

Although fundamentally different, density and specific gravity are, none the less, determined in the same way. Both terms are used synonymously to express the "heaviness" of a substance - in this case the metal in a coin, token, or medal. Density and Specific Gravity both describe the degree of weight concentration that a coin has by a number peculiar to the metal or alloy constituting it. The number is characteristic of the metal and remains constant, even for a well-worn coin. This is so because the number called density is derived by dividing the weight of a coin by its volume. As a coin wears away the weight and volume both reduce at the same rate, so that the density remains unaffected. Thus, although a coin is worn it is still possible to determine whether or not its specific gravity matches that of the alloy of a known-genuine piece, as an aid to authentication. A weight comparison would not be meaningful since an allowance for the amount of wear could not be accurately made in making a judgment of coin composition. The weight tolerance on uncirculated coins can vary several percent, making specific gravity of value in this case also.

This, then, is a quick look at the terms and one possible application. Before proceeding on, some groundwork of a basic nature is warranted, however, to be followed by the method for determining density or specific gravity and useful applications for the numismatist.

DENSITY

It is basic that coins struck in magnesium and in gold from the same dies would be vastly different in weight. Likewise, pieces in tin, silver, lead, nickel, etc., would have different weights, varying from each other, but within the boundaries of the light-weight and heavy-weight, magnesium and gold. If a way of expressing this attribute of heaviness, or relative weight concentration were available to the numismatist he would have a way to help assay the composition of a coin, having once determined this heaviness.

Density or specific gravity is the ready means for making this comparison, and doing it at no danger of damaging the coin. Both of these scales are based on the weight of water as a standard, or reference. The equal size coins in different metals in the foregoing example would be scaled by density by weighing also the amount of water needed to just fill the cavities of both dies. If the water were found to weigh two (2) grams the volume of both die cavities, (hence the coin volume) would be two (2) cubic centimeters, since in the International Metric System the gram is taken as the weight equal to the volume of one cubic centimeter (a cube 1 centimeter on a side - about 4/10 inch on a side, the size of a cube of sugar).

Knowing the weight of each coin and its volume the amount of weight concentration, or weight density (density, for short) can be expressed for each metal. If the aluminum and silver were found to weigh 5.4 grams and 21 grams, for example, their densities would be 5.4 grams/2 cu. cm., or, more simply, 2.7 gm/cu. cm. (aluminum), and 11 grams/2 cu. cm., or 10.5 grams/cu. cm. for the silver. Density can be expressed in a variety of ways - grams/cu. cm., pounds/cu. in., pounds/cu. ft., ounces/cu. in., etc. Numismatics uses the definition standard in laboratory type work - grams/cu. cm. In a formula, the expression is:

(Formula 1) $$\text{Density} = \frac{\text{Weight of coin in air}}{\text{Volume of coin}}$$

SPECIFIC GRAVITY

Specific gravity expresses the heaviness, or weight concentration of an object by comparing the weight of an amount of the object with the weight of an equal amount of water. Suppose that in our equal-sized coin example the weight of the water drained from the die cavities, rather than its volume had been used. Assume also that the weighings were made on a balance calibrated in grains rather than in grams, as follows: weight of aluminum coin - 83.3 grains; weight of silver coin - 324 grains; weight of die-cavity water - 30.8 grains. Now by definition specific gravity is a ratio of one weight to another, that is:

(Formula 2) $$\text{Specific Gravity} = \frac{\text{Weight of coin in air}}{\text{Weight of water equal to volume of coin}}$$

For the aluminum coin this is 83.3 grains/30.8 grains, or 2.7, and for silver, 324 grains/30.8 grains, or 10.5. These are the same numbers obtained for densities, using Formula 1, except that in this case no units are used. The specific gravity is simply a ratio expressing the weight of the coin as "times as heavy as the same amount of water". Any units of weight can be used, provided the same units are applied to both the coin and to its equivalent water volume weight.

TEMPERATURE AS A FACTOR(1)

Since both metals and liquids change in volume with changes in temperature it is important that a temperature reference be specified with the given density or specific gravity. Normal room temperature (20°C, 68°F) is the usual standard for metals. When density is given, water at 4°C is the standard, since the International Gram by definition is the weight of 1 cu. cm. of water at 4°C. When specific gravity is used it is usual for the value to be referred to water at its most dense condition, 4°C (39.2°F). Since varying interpretations cannot be given the term density, this is the preferable term. A correction factor can be readily applied to specific gravities (or densities) determined with room temperature water to correct them to the standard 4°C point, as will be discussed for typical calculations later on.

TABLED SPECIFIC GRAVITIES

Average Specific Gravities for a variety of pure metals and alloys applicable to the field of numismatics appear in Table I. These were compiled from various reference sources, as noted.

Small differences may exist in a given specific gravity for the same metal from one reference to another. These are due to variations in sample purities, different types of material not always defined (rolled, annealed, cast, etc.) and in the care used in determining the specific gravity.

Differences in weight between equal volumes of different metals or alloys are due to unlike weight concentrations of the material. The atoms vary from one element to another both in their individual weights and in their lattice structures. The latter refers to the three-dimensional pattern that determines how the atoms pack together - tightly bunched, uniformly spaced, or set up in layers or planes. The large variety in these factors is clearly shown in Table I. A great range exists - from magnesium at 1.74 to platinum at 21.4, with the popular coinage metals concentrated in the region of 8 to 12.

The specific gravities for alloys of gold, silver, lead, copper and aluminum in varying ratios appear in Curves 1-7. In each curve a straight line connects the specific gravities for the 100% (unalloyed) state of each metal as a reference. Data from available tables of specific gravity of various alloys of the two elements have been plotted, and the entire range is represented by a smooth curve based on these points. A broken line estimates the relation in regions not covered by available data. It is interesting to note that in general the specific gravities deviate from the equal proportion line, with the maximum accuracy near the 50/50 alloy point. In Curve 2, for example, a 50% lead - 50% tin alloy by the proportion line would have a specific gravity of 9.3 (mid-way between 11.35 (pure lead) and 7.3 (pure tin). The plotted data indicate, however, a specific gravity of only 8.9. This downward bow characteristic is especially pronounced in Curve 1, where a 50 Au 50 Cu alloy has a specific gravity about 15% below the proportion line value. In Curve 6 the graph for copper-zinc (brass) bows upwards, while the copper-tin, (bronze), Curve 5 closely follows the proportion line for alloys having up to 10% tin.

Specific gravity can be a valuable help in identifying the composition of a coin. It can be used to reject the authenticity of a coin, but not necessarily as an assurance of its genuineness. These and other applications will be considered after looking into the way that specific gravity is determined.

COIN VOLUME DETERMINATION

An important step in deriving the density or specific gravity from Formulas 1 and 2 is accurately determining either the volume of the coin or the weight of a volume of water equal to the volume of the coin. And this without defacing the coin by sampling or otherwise damaging the piece. Fortunately for numismatists the problem was solved millenniums ago by Archimedes, the noted Greek scientist. Reputed to have noted the rise in water upon his entering the bath he conceived the law of hydraulics bearing his name to this day. The "Law of Archimedes" states that an object partly or wholly immersed in a fluid loses weight equal to the weight of the fluid displaced. He used it when engaged to determine the fineness of a gold crown crafted for King Hieron II of Syracuse(2).

A practical demonstration of this law is in the perceptible increase in effort needed in hauling up an anchor as it starts out of the water. A useful analogy to the numismatic application is the following. Let us visualize a light weight hollow ball of magnesium filled with water, attached to a spring scale and lowered slowly into a barrel of water. The scale would read less and less as the ball lowered, settling at almost zero with the ball fully submerged. The water within the ball would now be held in suspension by the water. Now place the scale under the ball and pump the water from it. The scale would now show an increasing upward force on it, reading, with all water pumped out, approximately the same as the air-suspended weight, and indicating the buoyancy force of the water.

The suspended balls appear schematically in Fig. 1, showing the effects of water suspension upon a weightless (empty) ball filled with 1 Kg (2.2 lb) of water. At 50% water suspension the scale reads 50% of the air value, or 0.5 Kg (1.1 lb) and at the fully immersed, fully suspended condition, no weight at all. Archimedes' Law can now be put to use in determining the specific gravity of the contents of the assumed weightless ball. The weight of water displaced by the ball obviously, must be equal to the weight (in air) of the ball, since the ball is all water, and just duplicates the water it forced out of the way in its fully immersed condition. Modifying Formula 2 to incorporate Archimedes' Law, then results in:

(Formula 3) $$\text{Specific Gravity} = \frac{\text{Weight of object in air}}{\text{Weight of object in air - weight of object in water}}$$

Substituting the scale readings from Fig. 1 yields

$$\text{Specific gravity (of water)} = \frac{2.20\text{ lb}}{2.20\text{ lb} - 0\text{ lb}} = 1$$

In Fig. 2 the ball is made of a magnesium-aluminum alloy weighing 2 Kg (4.4 lb) in air. When submerged 50% (to its "equator") the scale reads 1.50 kg (3.3 lb) and at full submersion, 1 Kg (2.2 lb). Using Formula 3:

$$\text{Specific gravity (Mg-Al alloy)} = \frac{\text{Weight of object in air}}{\text{Weight of object in air - Weight of object in water}}$$

$$= \frac{4.4}{4.4 - 2.2} = 2$$

The specific gravity of 1 of the water reduced the weight of the ball by 50% when it was fully submerged. The above technique is the basic one used in determining the specific gravity of coins, tokens and medals, using appropriate weight units and a small correction factor for water temperature.

THE HYDROSTATIC WEIGHING ARRANGEMENT

The hydrostatic weighing method is generally used for determining the density/specific gravity of coins, tokens and medals. Meaning, literally, the "still water" method, the scheme can be used with a variety of laboratory balances. Figs. 3 and 4 show the two general arrangements for using an analytic balance to conveniently weigh the coin in air and while suspended in water. An auxiliary, or water pan is hung from the same beam point as the main, or air-pan. Many balances are equipped with a hook just for this purpose.

In Fig. 3 t single-pan beam balance is provided with a convenient adjustable platform between the pan bows to support a beaker of water in which the water-pan and the coin are suspended. An equal-arm type balance is arranged in Fig. 4 to have the waterpan attached to a bottom point of the air pan. If the base of the balance projects under the air pan it might be drilled to pass a support wire with generous clearance. If this is not possible a water vessel support platform might be arranged as in Fig. 3 provided pan bows can be used to give the needed room for the vessel. The Fig. 4 arrangement has the advantage that the diameter of the water container is not limited by the spacing of bows, as in Fig. 3. This makes pan access easier, and increases the clearance between pan and vessel to reduce the possibility of the pan rubbing against the wall. The Fig. 3 arrangement requires close attention to keeping the air pan free of an occassional water drop that may spill down during the removal of the coin from the water pan. Fig. 4 scheme is free from this possibility. Large module medals can be conveniently handled by Fig. 4 on an oversized pan, whereas this might be a problem with the Fig. 3 scheme.

The water pan should be designed to have a safe surface for coins and be supported by 3 wires meeting to join to a common fine wire up to the hook, to minimize tipping and touching of the vessel wall. Only the single vertical wire should pass through the surface of the water so as to minimize the error due to surface tension of the water on the wire. The pan should be concave so that coins will tend to move towards the center when placed into the pan with protected tip tongs. Some clear plastic or metal food containers can be made into serviceable pans. A bottom may be cut from a plastic-coated aluminum soup can, for example, to form a dish-like pan. This can be cold-worked with the end of a broom handle to form a concave bottom. To make it easier to grasp the coin with tongs a plastic pan might be used and have plastic knobs cemented around the inside surface to give space for inserting a tong under the coin. Some plastic may need weighting to keep it immersed and care should be taken to prevent air bubbles being trapped between the weights and the pan. It is important that the coin be arranged vertically when passing it into the water to prevent air bubble entrapment on its under surface. Air bubbles simulate a larger coin and create errors in the specific gravity determination.

SPECIFIC GRAVITY DETERMINATION

Three weighings are made to provide numbers for use in the weight/volume relationship for calculating the specific gravity. With the water pan properly immersed and the coin not in either pan a reading referred to as the null is made and recorded in the (No. 1) space on a data sheet, as arranged in Table II. The dry coin is now placed on the air pan, balanced, and the (No. 2) weight recorded. Then the coin is placed in the submerged water pan and the balance is restored and recorded (No. 3). The null balance is subtracted from the "coin and air pan" and "coin and water pan" weighings to give the weight of the coin above in air (A) and in water (W). The latter two are subtracted (A-W) to provide the buoyancy weight, (euqalling the coin volume) and this is divided into the coin weight in air $(\frac{A}{V})$ to provide the apparent specific gravity. A correction is obtained from Table III(1), corresponding to the closest figure in the table to the calculated apparent specific gravity. This is subtracted from the apparent specific gravity to give the true gravity. The foregoing sounds much more complex than it is in reality. A data sheet can be made up in columnar form to provide space for many determinations, using the common itemization in the left hand column to locate the appropriate posting line in each data column.

SPECIFIC GRAVITY AS AN AUTHENTICITY CRITERIA

By comparing the determined density with the published value a judgement can be made on the coin authenticity. If the density does not agree, the coin can be labeled a forgery. A reasonable allowance for inaccuracy in the determined value must be applied in making this comparison.

Assume for instance that authenticity of a ducat found to have a specific gravity of 16.45 is to be evaluated. The original is stated to be of gold-copper alloy of 875 fineness. If the specific gravity is not stated it can be approximated from Curve 1 as 16.70. The determined specific gravity differs from the alloy curve value by .25 out of 16.70, or 1.5%. If, from experience the accuracy of the determination is known to be within 1/2% of true and a 1/2% error allowance is made for the curve there still remains a 1/2% deviation. Conclusion - it is highly probable that the ducat is a counterfeit.

Specific gravity as an authenticating criteria is not reversible, however. That is, the fact of specific gravities in agreement does not in itself certify authenticity. If the determined specific gravity had been found to be 16.63, for instance, agreeing very closely with the standard of 16.70 this should not be inferred as proof of authenticity of the coin. One report$^{(3)}$, in the case of rare Greek coins indicates that forgers researched the compositions of the originals, duplicating them to have their product meet any test of specific gravity that might be made. If the specific gravities agree other areas must be used for making a judgement on the authenticity.

DETERMINATION OF ALLOY FINENESS

Most older silver coins are of binary alloy composition, i.e., they are of silver-copper content, with perhaps traces of other elements as impurities. Silver coins of the current century are not necessarily as simply constituted, and determination of their composition from their specific gravity alone is not feasible. If the quaternary alloy types of Sweden and the United Kingdom (Table I) are spotted on Curve 3 for silver-copper the effect of the nickel and zinc is apparent. For the determined specific gravities the Swedish piece, if considered as a silver-copper alloy would be indicated as 58 Ag 42 Cu, whereas these two elements are, in reality 40 Ag 50 Cu. Likewise, the British pieces would indicate 40 Ag 60 Cu - the true portions being 50 Ag 40 Cu.

The foregoing shows the impropriety of an assumption of a binary constitution for every "silver looking" coin. Coins struck before WWI, however, and having a characteristic silver appearance may reasonably be assumed to be of binary composition, with copper as the alloy.

Using this assumption a determination was made on a Brazil 960 Reis of 1814 as reported in Table II.

A reference to the plot of Silver-Copper alloy vs Sp. Gr., Curve 3, assigns a composition of approximately 960/40 for the determined specific gravity of 10.40. This is verification of the high fineness of these counterstruck Spanish pieces of eight Reales.

BALANCES

The author made all specific gravity determinations in this report (and many others too numerous to detail) on an accurate yet relatively inexpensive Ohaus balance(4) of the style shown schematically in Figure 3. He acknowledges with appreciation the loan of the instrument for this study by Mr. Raymond A. Byrne of Pittsburgh.

Coins and medals from 3 - 125 grams were weighed on a precision substitution type analytical balance of stated sensitivity and accuracy of 0.1 mg and used as a standard of comparison for their weights on the Ohaus Model 310. Values were found to be within the stated accuracy of the balance. The 0-10 gram dial with vernier provides convenient and quick readings. This balance should be included in any evaluation of instruments of 10 mg sensitivity for purchase by coin clubs or individual numismatists.

Valuable general information on definitions of terms describing the performance of analytical balances are given in a product catalogue(5) of the highly dependable Wm. Ainsworth & Sons, Inc. A complete line of high-accuracy balance is featured by this company.

ACCURACY OF RESULTS

The accuracy to which specific gravity is determined from one set of three weighings is much less than the accuracy possible in determining the coin weight alone. To illustrate, assume that the specific gravity of a 10.00 gram silver coin is determined by the hydrostatic method (in one set of readings) to be 10.17, using a balance having 10 milligrams (.010g) stated accuracy. How much reliance can be placed in this determination? Is the true specific gravity within 1/10 of 1% of 10.17, (the accuracy of weight measurement represented by 10 mg in 10 grams, the stated accuracy of weight measurement)? To evaluate the worth of the determined specific gravity we can assume maximum and minimum weight indications for a specific gravity of 10, as follows:

$$\text{Min. Sp. Gr.} = \frac{\text{max. wt.}}{\text{max. wt. - min. wt.}} = \frac{10.01}{10.01 - 8.99} = \frac{10.01}{1.02} = 9.81$$

$$\text{Max. Sp. Gr.} = \frac{\text{min. wt.}}{\text{min. wt. - max. wt.}} = \frac{9.99}{9.99 - 9.01} = \frac{9.99}{0.98} = 10.19$$

This means that the tolerance on a determined specific gravity of 10 for a 10 gram coin is ±.19, or ±1.9%. This is 19 times less accurate than a single weight measurement! Applying this tolerance to the determined specific gravity of 10.17 gives the true specific gravity as being within the range of 9.98 to 10.36.

Results of calculations in this manner for imaginary coins of 5, 10 and 20 grams weight and 5, 10, 15 and 20 specific gravity appear in Table IV. From the tabled results the following deductions are made:

1. For coins of the same weight, but of different metals, the specific gravity tolerance increases in proportion to the increase in specific gravity. Example: A 5 gram coin of specific gravity 20 has an 8% tolerance - two times that of the silver coin of Sp. Gr. 10, at 3.8%.
2. For coins of the same specific gravity, but of different weights the specific gravity tolerance increases in proportion to a decrease in coin weight. Example: A coin of Sp. Gr. 10 weighing 20 grams has a Sp. Gr. tolerance of 0.9%, while a coin half as heavy (10 grams) has double the tolerance (1.9%).

Table IV has been divided into two parts to show the increased inaccuracy inherent in determining Specific Gravity of lighter coins having high specific gravity (silver, gold), and the advantage of heavy coins over lighter ones.

One might question the value of specific gravity determinations based on the apparent high inaccuracies, especially for lighter coins of high specific gravity (silver and gold). The tolerances can be greatly reduced (confidence in the value increased) by making many determinations and using themean, or average of these results. The mean is the best measure of central tendency mathematically available, and will more closely approach the true specific gravity as the number of determinations increases. Five or six determinations would appear to be a reasonable number for smaller coins and three or four a suitable number for the larger crown sized pieces. By calculating the specific gravity for one trial and the mean for 2, 3, 4, etc., determinations one could obtain an idea of a reasonable number of determinations needed.

It should be recognized that Table IV is based on use of a 10 mg accuracy balance, - not a particularly accurate instrument. For those fortunate enough to have use of a balance of greater accuracy the table would be correspondingly reduced in tolerance, and fewer determinations would be required for averaging purposes. For a 1 mg. (.001g) accuracy balance, for instance, by using the technique previously described the tolerances in Table IV would be found to be only 1/10 of those shown. The 10 gram, Sp. Gr. 10 coin of the previous example would have a specific gravity tolerance of 0.19% for one determination, rather than 1.9% as for the 10mg balance.

CONCLUSION

This paper is only an introduction to the possibilities for the use of this highly valuable coin attribute - specific gravity. The author, based on his brief encounter with Spanish silver fineness described herein, can only feel that the use of specific gravity measurements in key areas would provide a new wealth of numismatic knowledge. Information on the fineness of the many escudos so completely described in a recent article(6) on the 1715 Spanish galleon gold, for example, might lead to new facts about the sources or the distribution of gold to the various new-world mints. Coins with illegible mint marks might take on new meaning through identification with an alloy peculiar to a particular mint.

Much numismatic knowledge can be gained though the medium of specific gravity. The cited references should be a good start for those interested in digging deeper.

APPENDIX

REFERENCES

1. Peter Hidnert and Elmer L. Peffer, Density of Solids and Liquids, National Bureau of Standards Circular 487, Washington: U. S. Department of Commerce, March 1950.
2. L. Sprague de Camp, The Ancient Engineers, Norwalk, Connecticut: The Burndy Library, 1966.
3. C. L. Woolley, "The Complete Forger", Hands on the Past, C. W. Ceram, Editor, New York: Alfred A Knopf, Inc., 1966.
4. Precision Balances and Weights for Science Education and Industry, Catalogue H, Ohaus Scale Corporation, 1050 Commerce Avenue, Union, New Jersey 07083.
5. Wm. Ainsworth and Sons, Incorporated, Balancc and Weights, Catalog A2-15, Wm. Ainsworth and Sons, Inc., 2151 Lawrence Street, Denver, Colorado.
6. W. Frank Allen, "Previously Unknown Spanish Gold Coins", The Numismatist, Vol. 80, No. 2, American Numismatic Association, Oak Park, Illinois, February, 1967.

Table I

Average Specific Gravity for Metals and Alloys of Numismatic Interest

Specific Gravity is for the metal at 20°C (68°F) and referred to water at 4°C (39.2°F), corresponding to Density in gm/cm^3.

Metal/Alloy	Symbol	% Composition, Fineness	Specific Gravity	Source	Notes
Platinum	Pt	990 plus	21.37	a	
Gold	Au	999.9	19.32	b	
Gold-Copper		900/100	17.16	a	Curve 1
Lead, Chemical	Pb	99.9 Pb .06 Cu	11.34	a	
Silver	Ag	999 plus	10.50	b	
Lead-Tin		77.8 Pb 22.2 Sn	10.05	a	Curve 2
Silver-Copper		900/100	10.3	f	Curve 3, U. S. Coinage
Silver-Alloy		40 Ag 50 Cu 5 Ni 5 Zn	9.48	h	Sweden
Silver-Alloy		50 Ag 40 Cu 5 Ni 5 Zn	9.45	h	UK 1920-46, Others
Bronze		95 Cu 4 Sn 1 Zn	8.96	a	U. S. Coinage
Nickel	Ni	99.99	8.91	b	
Copper	Cu	Pure	8.92	b, mean of c & g	
Nickel			8.60-90	a	
Cupro--Nickel		75 Cu 25 Ni	8.94	Curve 4	Curve 4, U. S. Coinage
Copper-Tin (Bronze)		90 Cu 10 Sn	8.78	a	Curve 5
18% Nickel Silver (German Silver)		65 Cu 18 Ni 17 Zn	8.75	a	Portugal, Philipines, Taiwan

Table I (Continued)

Metal/Alloy	Symbol	% Composition, Fineness	Specific Gravity	Source	Notes
Copper-Zinc (Brass)		70 Cu 30 Zn	8.56	e	Curve 6
Columbium	Nb		8.4	a	
Stainless Steel			7.8 - 8.0	f	Italy, Turkey
Iron	Fe	Pure	7.85-7.88	a	
Copper-Aluminum (Aluminum bronze)		90 Cu 10 Al	7.69	a	Curve 7
Tin	Sn	99.9 plus	7.29	b	
Zinc	Zn		6.92-7.19	a	
Antimony	Sb		6.65-6.72	d	
Aluminum	Al	Commercial 2S	2.71	g	
Magnesium	Mg		1.74	g	

Source Code:

a. Handbook of Chemistry & Physics, 43rd Ed., Chemical Rubber Pub. Co., Cleveland, 1961.

b. Properties of some Metals & Alloys, International Nickel Co., Inc., New York, 1953.

c. Copper Wire Tables, NBS Handbook 100, U. S. Dept. of Commerce, 1966.

d. A Textbook of Inorganic Chemistry, Vol. VI, C. Griffin & Co., Ltd., London, 1936.

e. U. S. Bureau of Standards, Scientific Paper 410.

f. Treasury Staff Study of Silver & Coinage, U. S. Treasury Dept., Washington, 1965.

g. Metals Handbook, American Society for Metals, Cleveland, 1939.

h. Investigations of John A. Nelson, Pittsburgh, 1967.

Table II

Recording of Weighings and Calculation of Specific Gravity for Brazil, 960 Reis, 1814

(2)	Wt in air pan	29.72	(3)	Wt in water pan	27.06
(1)	- Tare	2.21	(1)	- Tare	2.21
	Wt in air	27.51		Wt in water	24.85
	- Wt in water	24.85			
	(buoyancy)	2.66			

$$\text{Apparent Sp. Gr.} = \frac{\text{Wt. in air}}{\text{Wt. in air} - \text{wt. in water}} = \frac{27.51}{2.66} = 10.41$$

Water temperature correction (Table III) - 0.01

True Sp. Gr. 10.40

Table III(1)

Corrections to be applied to apparent specific gravities in order to obtain true specific gravities at 25°/25° (sufficiently accurate for practical purposes at ordinary room temperature) 16.0 - 21.0 added by J. A. Nelson.

Apparent Specific Gravity	Correction	Apparent Specific Gravity	Correction
2.0	- .0012	12.0	- .0130
3.0	- .0024	13.0	- .0141
4.0	- .0035	14.0	- .0153
5.0	- .0047	15.0	- .0165
6.0	- .0059	16.0	- .0177
7.0	- .0071	17.0	- .0188
8.0	.0082	18.0	- .0200
9.0	.0094	19.0	- .0212
10.0	.0106	20.0	- .0224
11.0	.0118	21.0	- .0235

Table IV

Specific Gravity Tolerances for a Single Determination made with a Balance of 10 mg (0.010 gm) stated accuracy.

Coin Specific Gravity	Coin Weight in Grams					
	5		10		20	
	Sp. Gr.	%	Sp. Gr.	%	Sp. Gr.	%
5	.10	2	.04	.9	.02	.4
10	.38	3.8	.19	1.9	.09	.9
15	.89	6.0	.43	4.3	.41	1.4
20	1.6	8.0	.78	7.8	.37	1.8

inaccuracy of 2% or less

inaccuracy of more than 2%

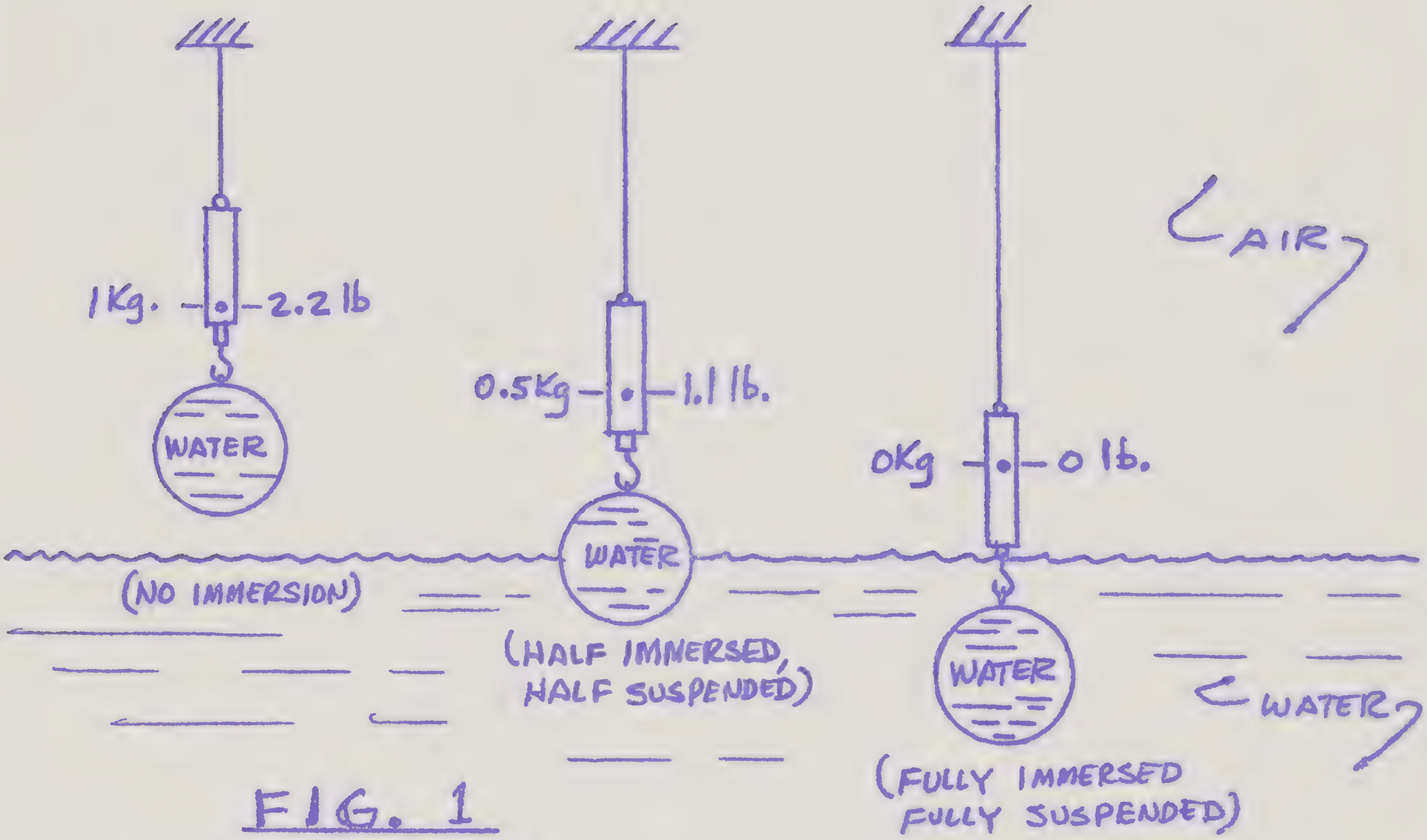


FIG. 1
WATER BALL, S.G. =1

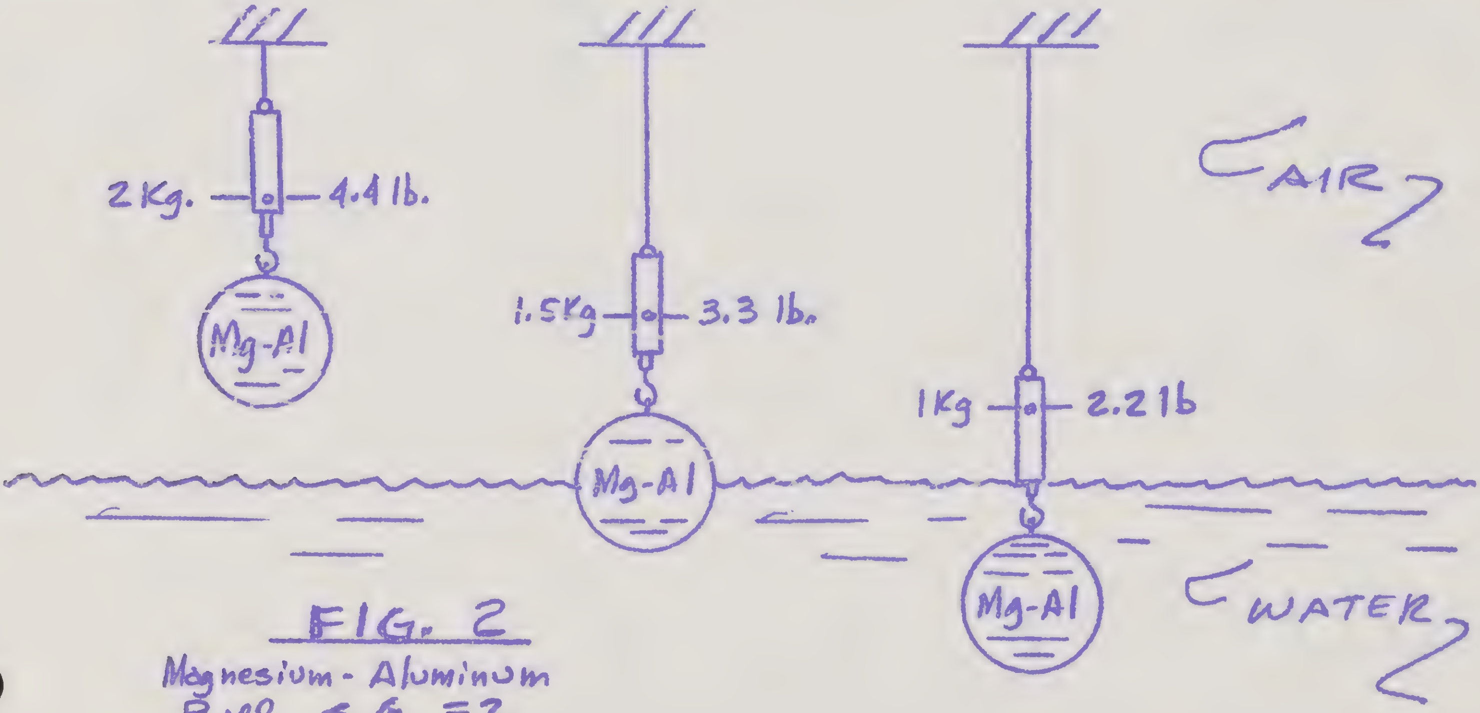


FIG. 2
Magnesium - Aluminum
Ball, S.G. =2

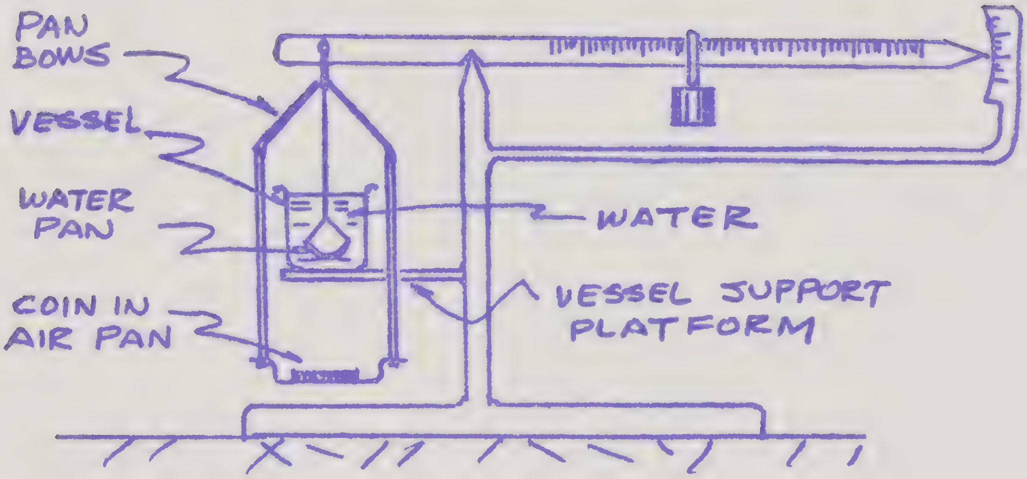


FIG. 3

WATER-PAN OVER AIR-PAN ARRANGEMENT - USING SINGLE PAN BEAM BALANCE

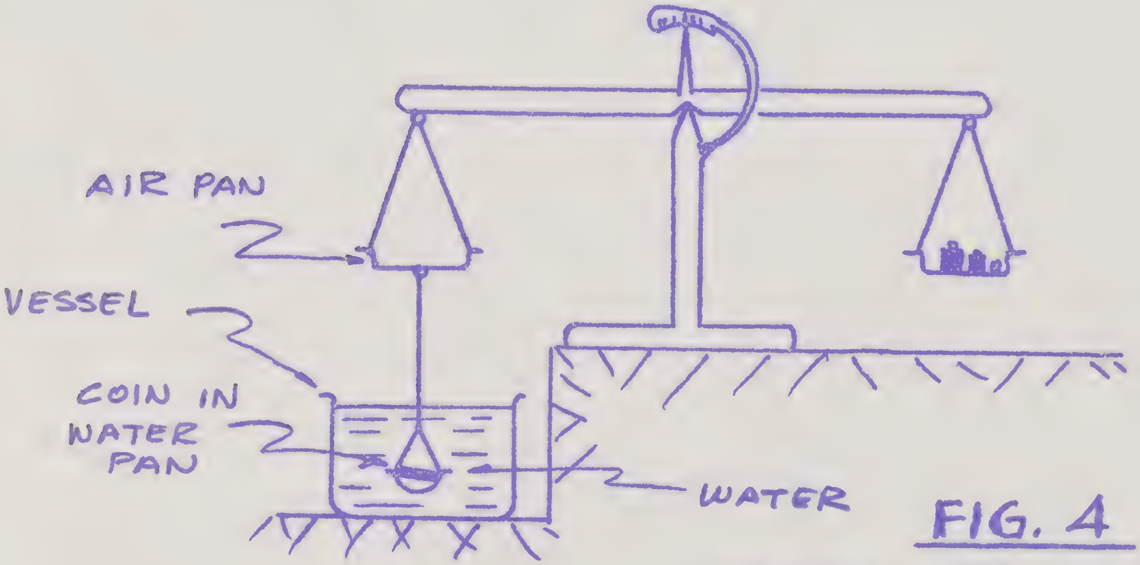
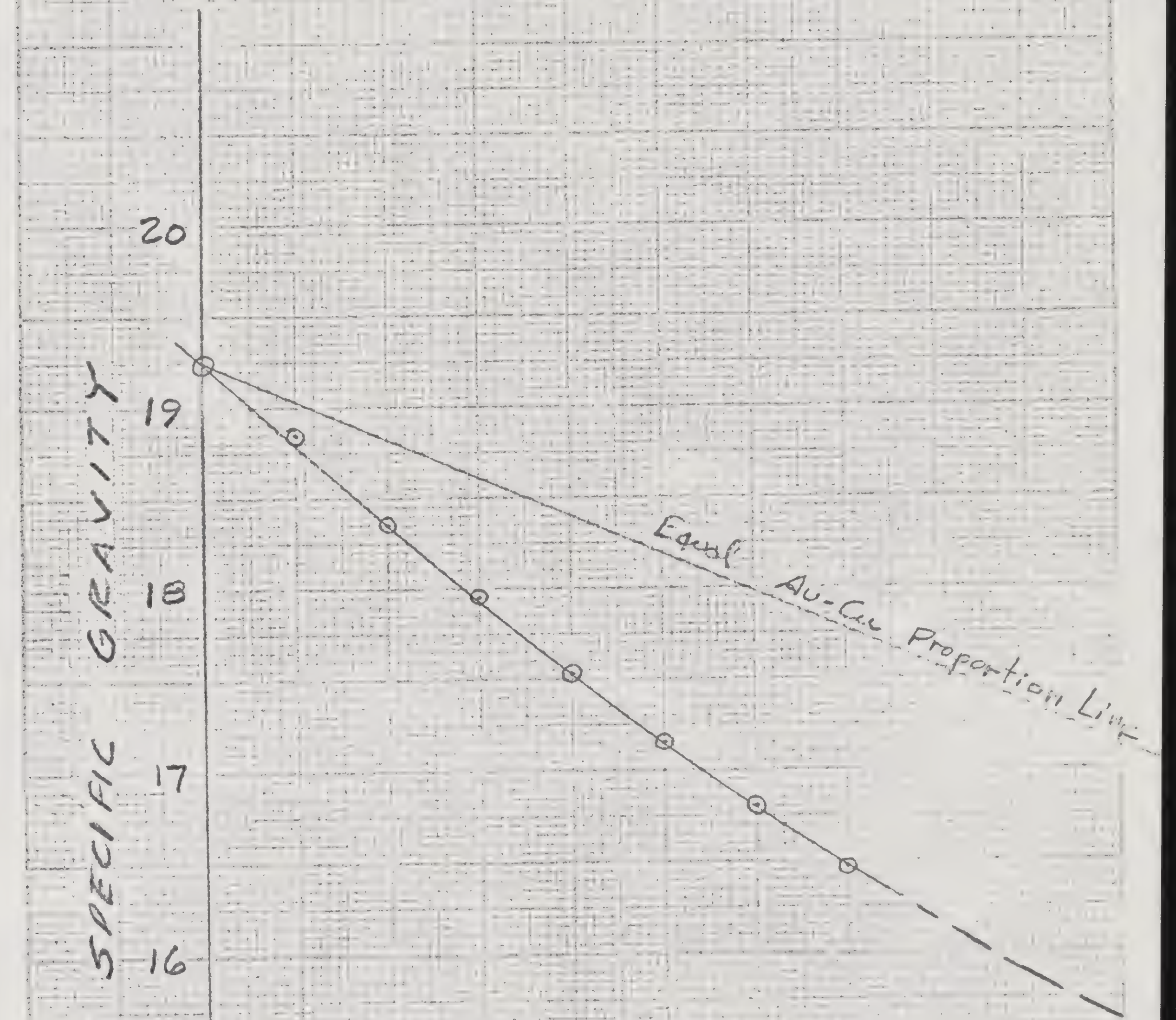


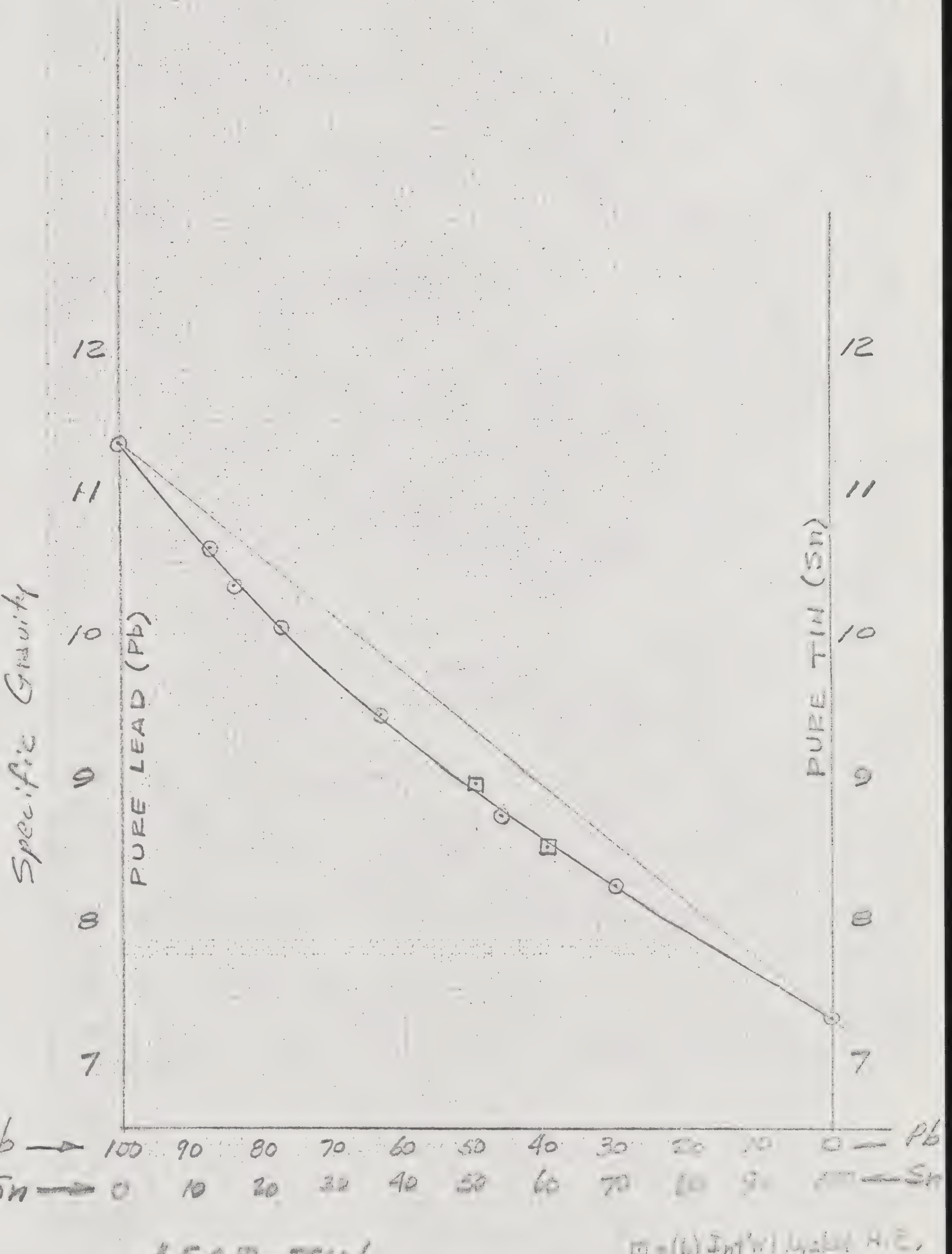
FIG. 4

AIR-PAN OVER WATER-PAN ARRANGEMENT - USING EQUAL-ARM BEAM BALANCE



GOLD - COPPER

SIGNATURE ______ DATE ______ CURVE 1



LEAD-TIN
(SOLDER)

▣ = (b) Int'l [illegible] H.E.,
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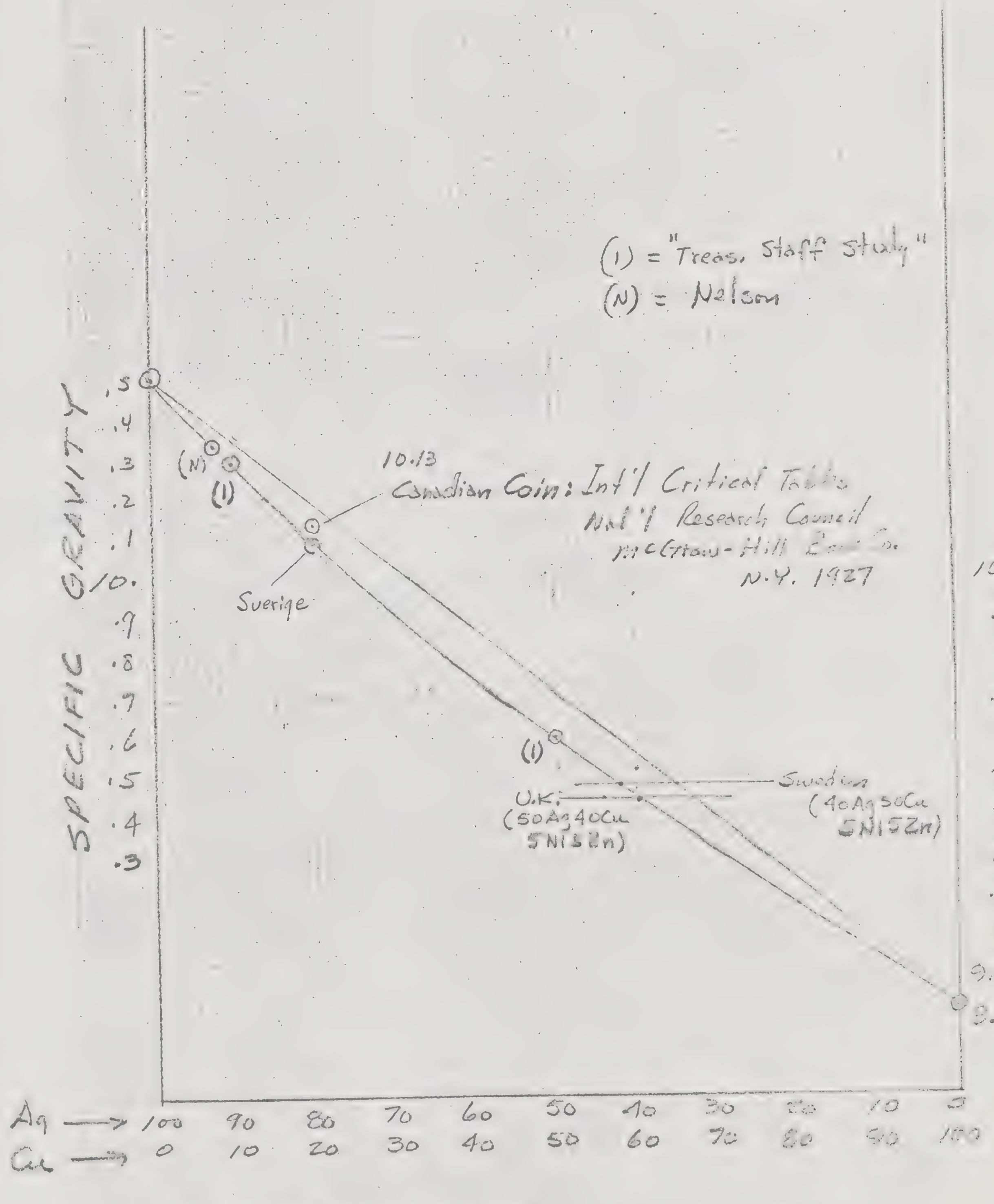
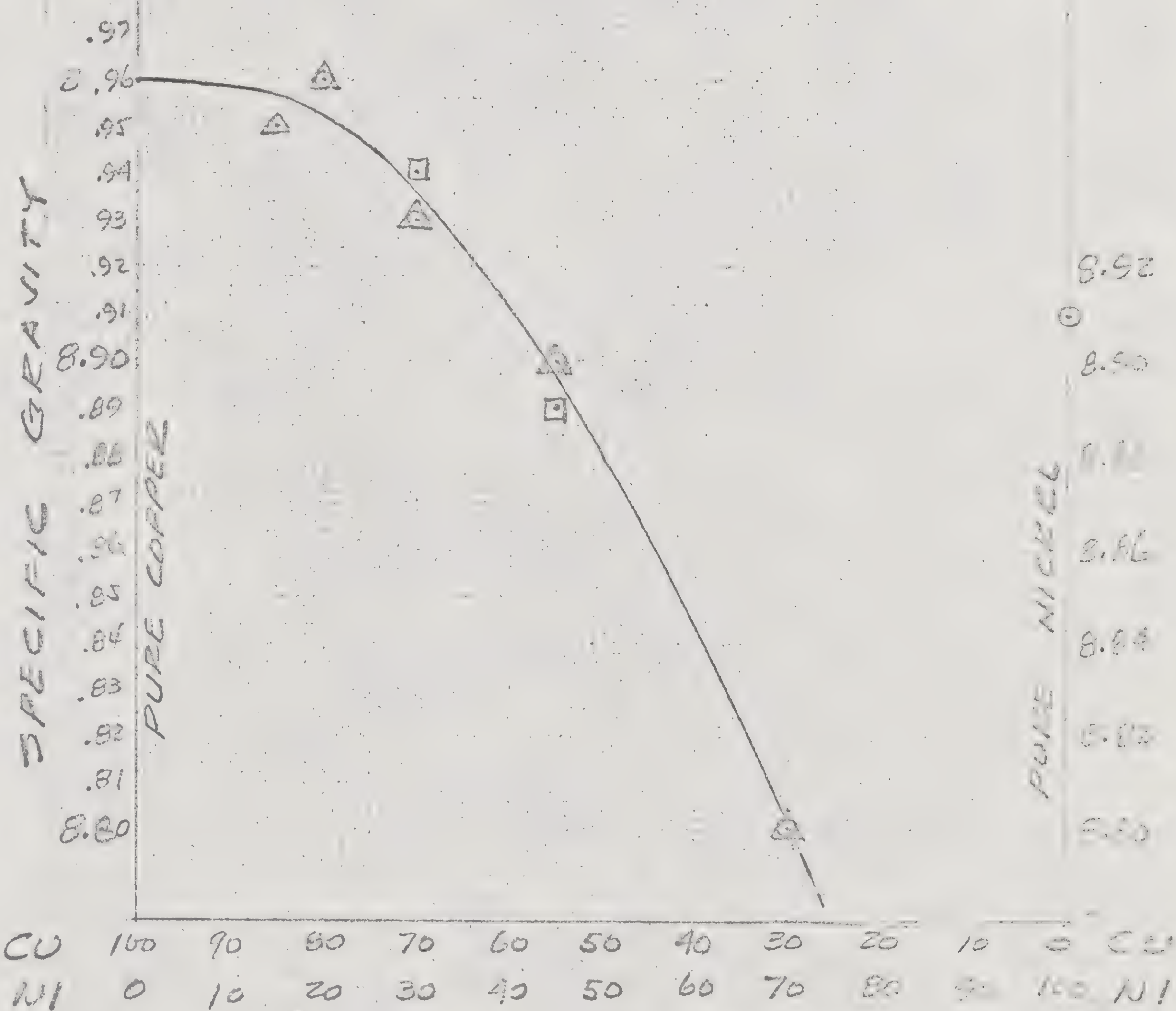


SILVER - COPPER

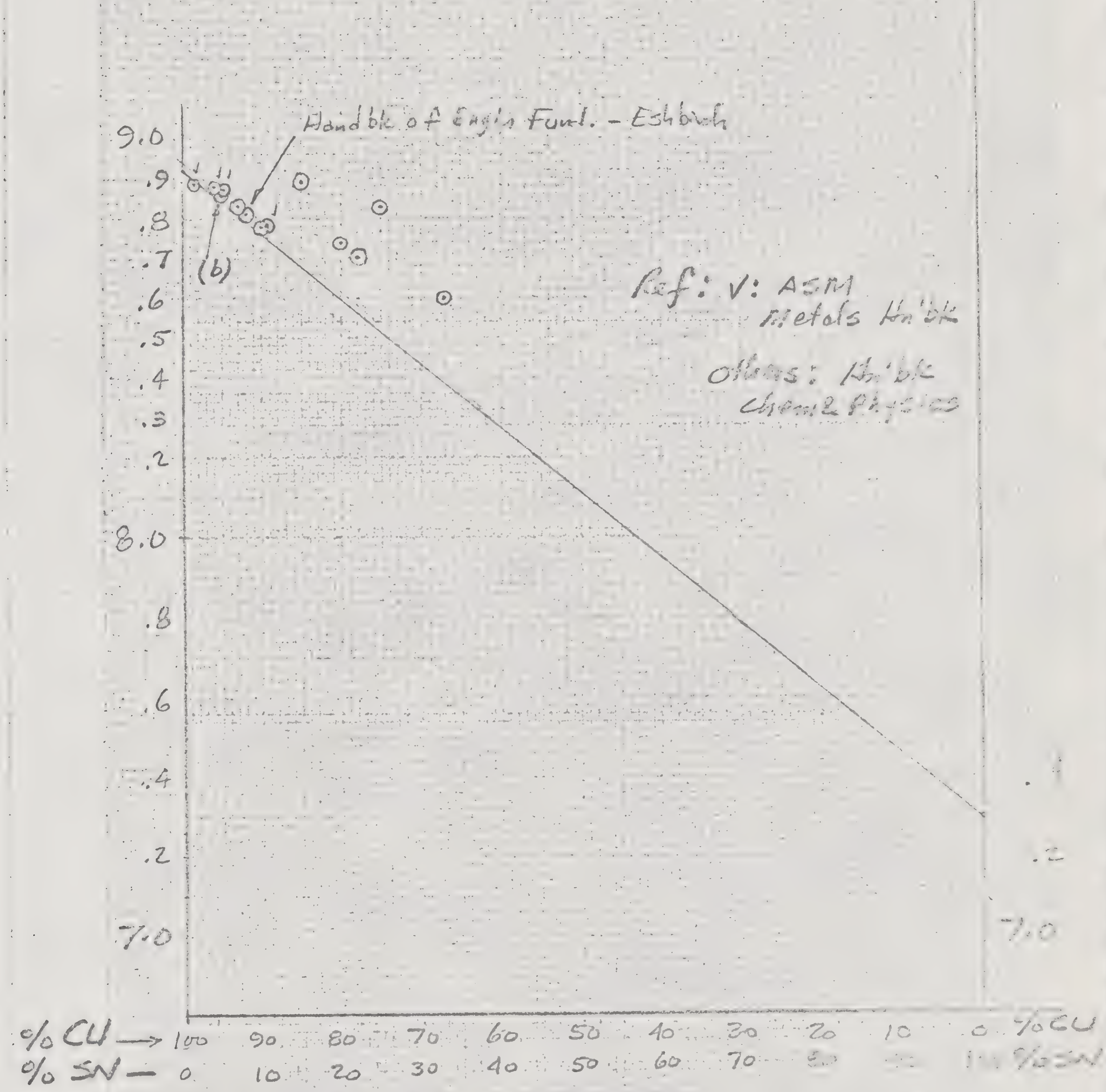
Ag - Cu

CURVE 3.



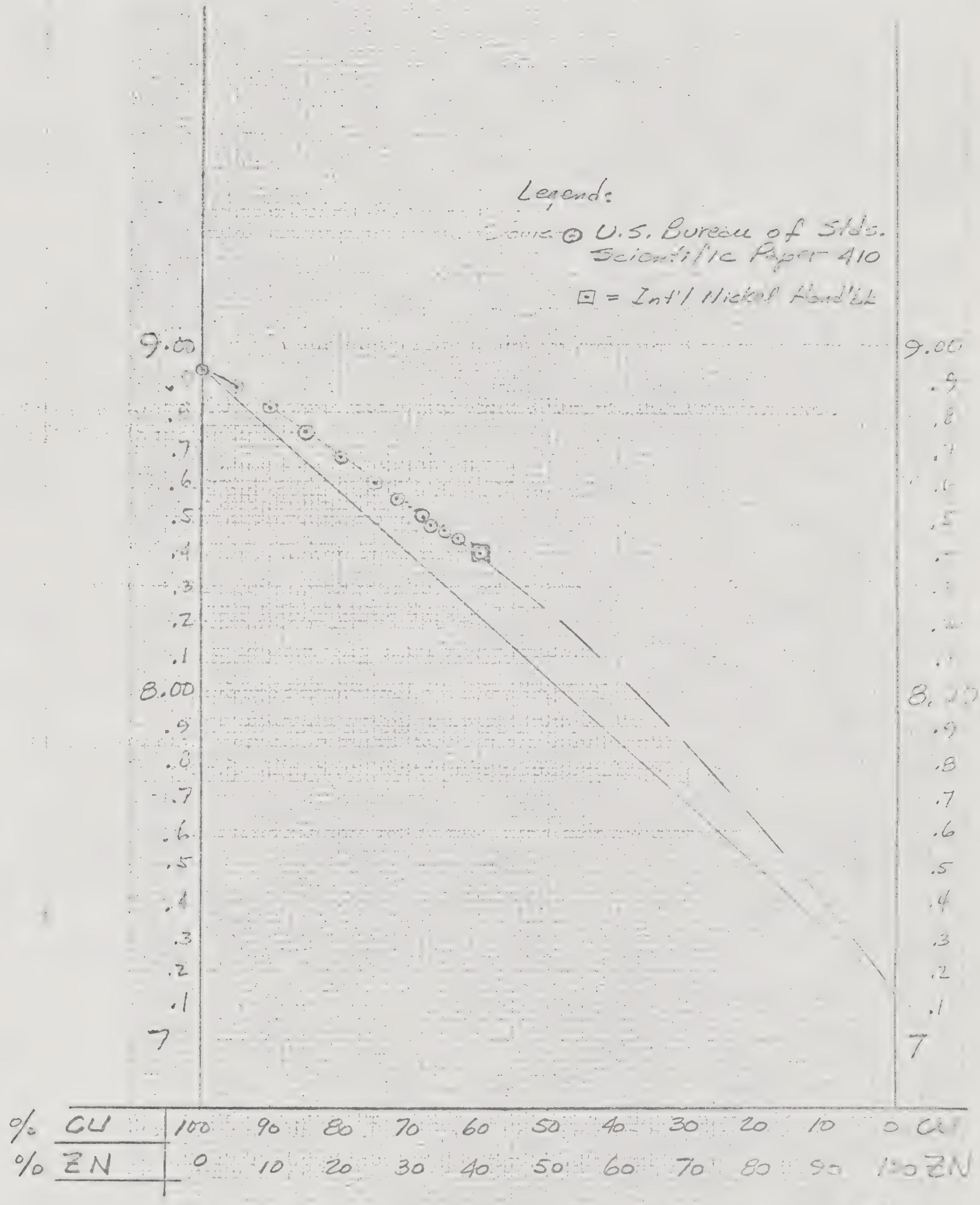
CUPRO-NICKEL

CURVE 4



COPPER-TIN (BRONZE)

CURVE 5

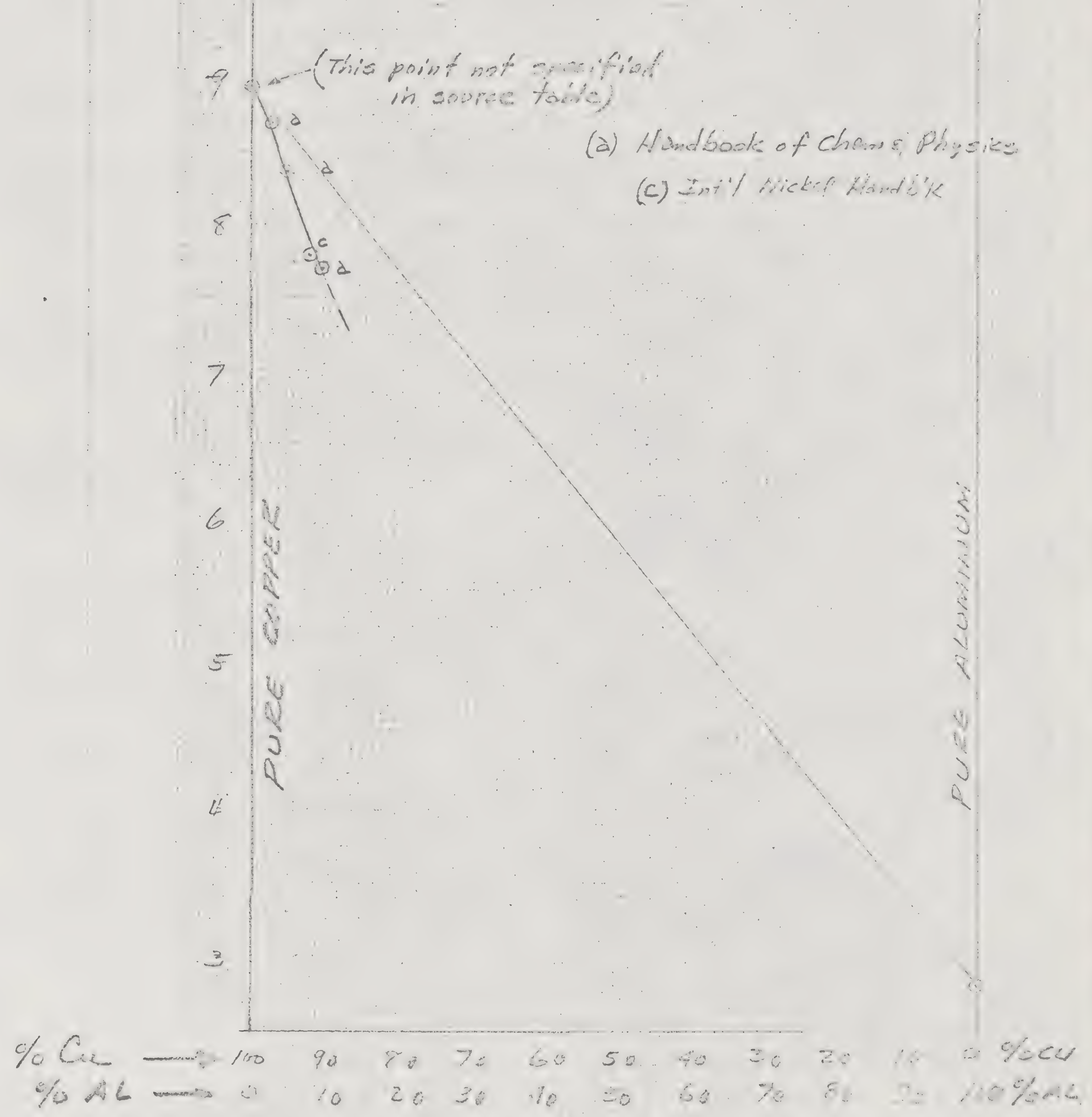


COPPER-ZINC

(BRASS)

CURVE 6.

Cu-ZN



COPPER-ALUMINUM
(ALUMINUM BRONZE)

CURVE I.

HIGH INTENSITY LAMPS IN NUMISMATICS

by

John A. Nelson
ANA R 56559

October 1969

HIGH INTENSITY LAMPS IN NUMISMATICS

The recent spate of lamps billed as "high intensity", along with their good application to numismatics has prompted this topic for presentation. It is only a survey, not a detailed study. Main features are described and things to evaluate when shopping are pointed out. Performance curves for various lamp parameters are presented in the appendix.

1. What They Are

High intensity lamps are miniature-sized lamps having bulbs that produce light more efficiency than conventional 120 volt size light bulbs. This light is usually concentrated by a shade into a smaller area than found with 120 volt household lamps. The advantages are derived from inexpensive automotive type low-voltage lamps, in most cases, for reasons to be mentioned. The basic nature of concentrated light from a small, relatively cool lamp has immediate advantages to the numismatist, who is ever-searching for better illumination of his coins.

2. Bulbs Used

Most high-intensity lamps use standard 12-volt bayonet-base automotive bulbs, types 93, 1141 or 1073, and a few, 6 volt, type 1133. Design data appear in Table I, showing that a great span in bulb light production (candlepower or lumens) exists. For all practical purposes the light output is proportional to the input wattage, so that the higher wattage (and current) bulbs of the same voltage, produce more light. The 6-volt bulbs have the highest rating (35 CP, 440 lumens) but, because of their high current and wattage, lamps using them usually carry a higher price tag than their 12-volt cousins.

3. Low Voltage Benefits

It is not intended to delve deeply into a complicated explanation of the reasons for the benefits of higher output for a given watt input of a low voltage bulb over a standard 120 volt household type. A few words are warranted, however. The higher the temperature of a tungsten filament in an incandescent lamp the more efficiently light is produced, and the whiter is the light as the radiation is shifted to the shorter visible wavelengths. A filament design is complex, requiring the correct diameter, length, coiling and support to produce the most light possible for its rated wattage. As shown in figure 2 a heavier, shorter filament is required for reduced voltage design of a given wattage bulb. This means that for a given wattage the filament can be housed in a smaller glass envelope. A second benefit is that because of use of two supports only for the filament it is not cooled as much as in a 120-volt lamp, and, together with a lowered loss of heat by gas conduction, produces more light for a given wattage than a 120 volt design does. This increase in efficiency with lowered design voltage is shown in Fig. 3. Figure 4 shows that 440 lumens of light can be produced by a 12 volt bulb at 24 watts energy, whereas a 120 volt lamp requires over 38 watts, or 160% more power. This means that in addition to being smaller, the high intensity low-voltage bulb also runs cooler (62% as much heat). (As mentioned later, however, most lamps use power transformers to supply the lower voltage and these dissipate perhaps 1 to 3 watts; slightly reducing the apparent heat saving above.)

4. Lamp Shades

To obtain a higher concentration of light than in common 120 volt "gooseneck" student lamps the high intensity bulbs are generally housed in a closely-fitting shade to reflect highly concentrated light from as close as possible to the filament and to minimize the lamp size. Although, as stated earlier, these bulbs do have less waste heat than their 120 volt counterparts they still do produce heat. The surface temperature of the glass envelope is very high, as is quickly discovered in touching a hot bulb. Good shade design requires adequate cooling to prevent its distortion or melt-down. Frequently a concentric shade arrangement is used, with the inner one of metal to reflect light and to conduct, to reflect and to radiate heat. The outer shade may be of plastic and will be relatively cool to the touch since the air between it and the metal inside shade acts as an insulating blanket. Some lamps use only one metal shade and this will operate quite hot. Examine the shade then, to see if it is a safe design and well cooled. It might be wise to check a lamp that has been operating for an extended period to see if any odd smells or distortions result from bulb heat.

5. Transformer-Powered Lamps/Loading

A 120 volt to 6 or 12-volt transformer is usually used to supply the rated voltage at rated current to the particular bulb used. Table I shows that design currents for 12 volt bulbs vary from a minimum of 1.04 amperes for bulb no. 93 to a maximum of 1.9 amperes for no. 1073. A well-designed lamp will have a compatible transformer to supply correct voltage and current to a particular bulb. The relatively small transformer for the no. 93 bulb as load would be seriously overloaded if a no. 1073 were substituted, for example. Although the overload would drop the voltage by about 1 volt the current would still increase greatly, and in less than a half hour or so the transformer would be too hot to touch, and the insulating varnish possibly close to the melting point, with transformer turns ready to short circuit. The warnings on most high intensity lamps are not manufacturers attempts at more bulb sales--they are valid warnings against possible damage. Use of a smaller load (wattage) bulb would not overload the transformer, but might mean higher than design voltage to the bulb. As shown in Fig. 1 a 5% increase over rated bulb voltage would decrease the bulb life to about 55% of its rated life. Most automotive bulbs are designed for 500 hours(2) operating life, so that the overvoltage would mean many hours off the life of the bulb. It is prudent, then, to use only the bulb for which the lamp is designed.

6. Variable Intensities

Most transformer-powered lamps have a LOW-OFF-HIGH switch to provide a lower light intensity, if desired. This is accomplished by changing in LOW to an increased turns position on the transformer primary winding to produce a lower secondary voltage. Fig. 1 shows that at 95% voltage the light output is decreased to 85% and the bulb life is extended to 185% of design life. Some transformer units are supplied with a much lower voltage so that the lamp may double as a night light.

A one-wire low voltage circuit is commonly used in 12 volt lamps. The automotive type lamps are designed for the car body as a "common negative" direct current (DC). Although the bulbs operate on alternating current in high intensity lamps one side of the circuit may be completed by using the metal between the transformer in the base and the shell of the bayonet socket in the lamp head. This system causes no danger to the user, being similar to the scheme used for powering toy locomotives by transformer.

7. Solid-State Power Supplies

Newer high intensity lamps use solid state components to provide lower voltage without the weight, heat and possible slight hum of a transformer type. A rotary dial or multi-position switch can supply smooth or stepped control voltage from a transitor to a silicon controlled rectifier (SCR) to control the conduction time (over the 60 cycle wave) that the bulb receives voltage. These lamps have electronic age components in their bodies but still produce light from the same style bulbs used in the transformer types.

B. Lamp Neck Styles

A wide variety of lamp neck styles are available to the numismatist. Some designs may be perfectly suitable for one particular use, but ruled out for others. Roughly speaking, designs may be typed into three categories: flexible, telescoping and grasshopper.

The flexible type necks are made of miniature diameter interlocking spiral ("Greenlee" or "BX") type conduit. These are simple, rugged, have no sliding sections or bending joints and provide maximum protection to the internal wire to the bulb. This type permits positioning the head in exactly the desired position for lighting an exhibit case or providing side lighting in coin photography.

The telescoping types are of round or square cross-section tubing, commonly made in two or three pieces. Sliding contacts are made between neck sections to provide a conduction path on one side of the circuit to the bulb socket. In addition, a potential trouble source is the wear on the pigtailed internal wire from repeated compression and extension of the neck telescope. This design, however, has the advantage of taking less packing space than a flexible type, and is particularly attractive in this regard. The shade on some types sit on top of the cylindrical body when compressed and take up not much more traveling space than a two-cell flashlight.

The grasshopper type is as implied. Articulated square or round tubing sections are connected by rivets or screw type hardware to permit adjustment of the head position. Experience has shown that a careful look at joint fabrication is well worthwhile. Riveted pins have a discouraging way of loosening up and are extremely touchy in tightening by light tapping. One might then have a problem of trying to release a too tightly tapped rivet. These joints must also carry the load current to the lamp and could be a source of trouble.

9. Conclusion

It is hoped that this survey of high intensity lamps may be helpful to the shopping numismatist. It should allow him to ask meaningful questions when looking for just that right lamp for his coin lighting application.

10. References

1. A. E. Knowlton, Ed., *Std. Handbook for Electrical Engineers*, 8th Ed., 1949, McGraw-Hill Book Co., Inc., N. Y.
2. Pender, Del Mar, Eds., *Electrical Engineers' Handbook*, 4th Ed., 1953, John Wiley & Sons, Inc., N. Y.

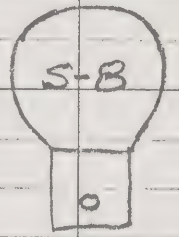
WORK SHEET
WESTINGHOUSE FORM 8295 E

TABLE I

6 AND 12-VOLT HI-INTENSITY LAMPS

LAMP NO.	TYPE	RATED VOLTS	RATED AMPS	RATED HRS.	CALC. WATTS	RATED CP	LUMENS[a]	Lum/W	Contacts
93	S-8	12	1.04		12.5	15	188	15	Single.
1141	S-8	12	1.48	500[b]	17.7	21	264	14.9	"
1073	S-8	12	1.9		22.8	32	402	17.6	"
1133	RP-11	6.2	3.91	200[c]	24.2	35	441	18.2	"
Others:									
6	S-8	6.4	3.0		19.2				Double
1493	S-8	6.5	2.75		17.9				"

Type Profiles:



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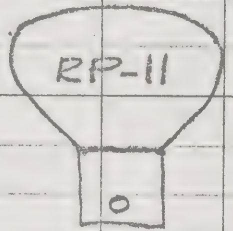

(Dia = 1 3/8 in.)

NOTES: a. Lumens = 4πCP = 12.57CP
b. Pender, Delmar, EE. Hndbk
c. Tensor leaflet

120 VOLT LAMP DATA (FOR COMPARISON)

WATTS	Eff. in Lumens per Watt	Lumens
6	6.6	40
10	7.8	78
25	10.4	260
40	11.6	465
60	13.9	835
100	16.2	1620
150	17.3	2600
200	18.2	3650

FORM 1788

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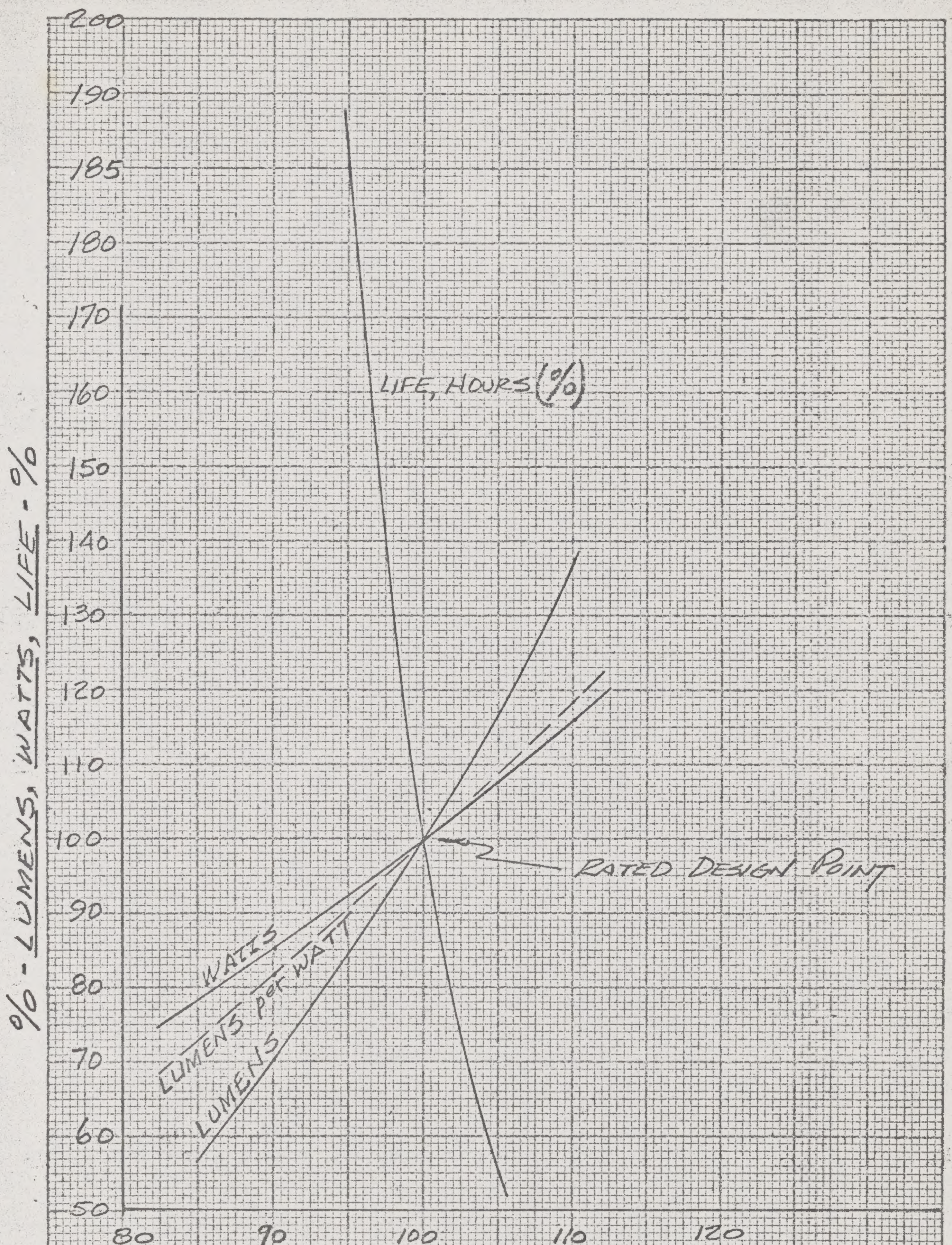

FIG. 1

(1) TUNGSTEN-FILAMENT INCANDESCENT LAMP CHARACTERISTICS

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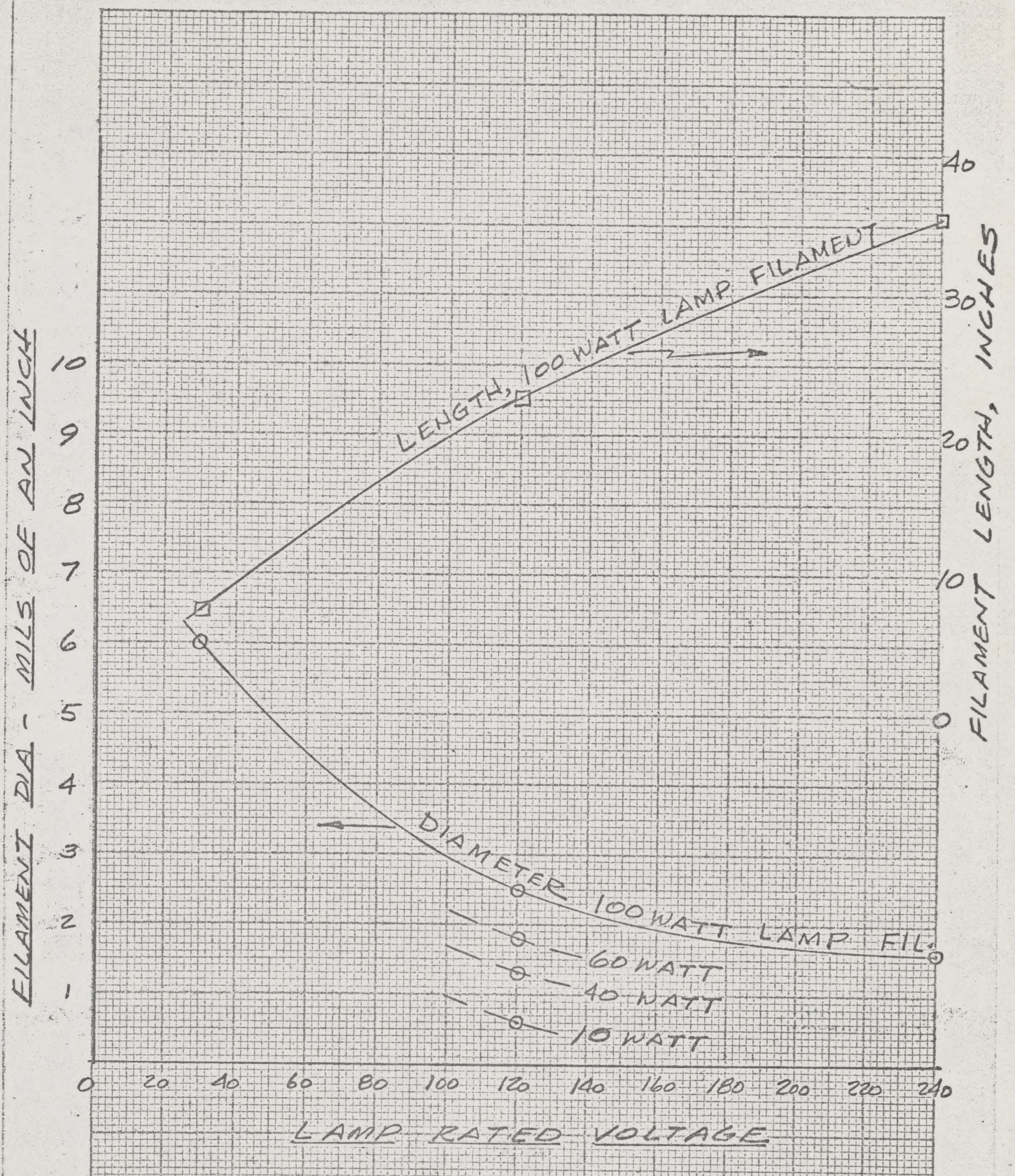

(2) FIG. 2.
VARIATION OF FILAMENT DESIGN
DIAMETER OF VARIOUS WATTAGE
LAMPS AT DIFFERENT DESIGN
VOLTAGES

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FORM 1705 B

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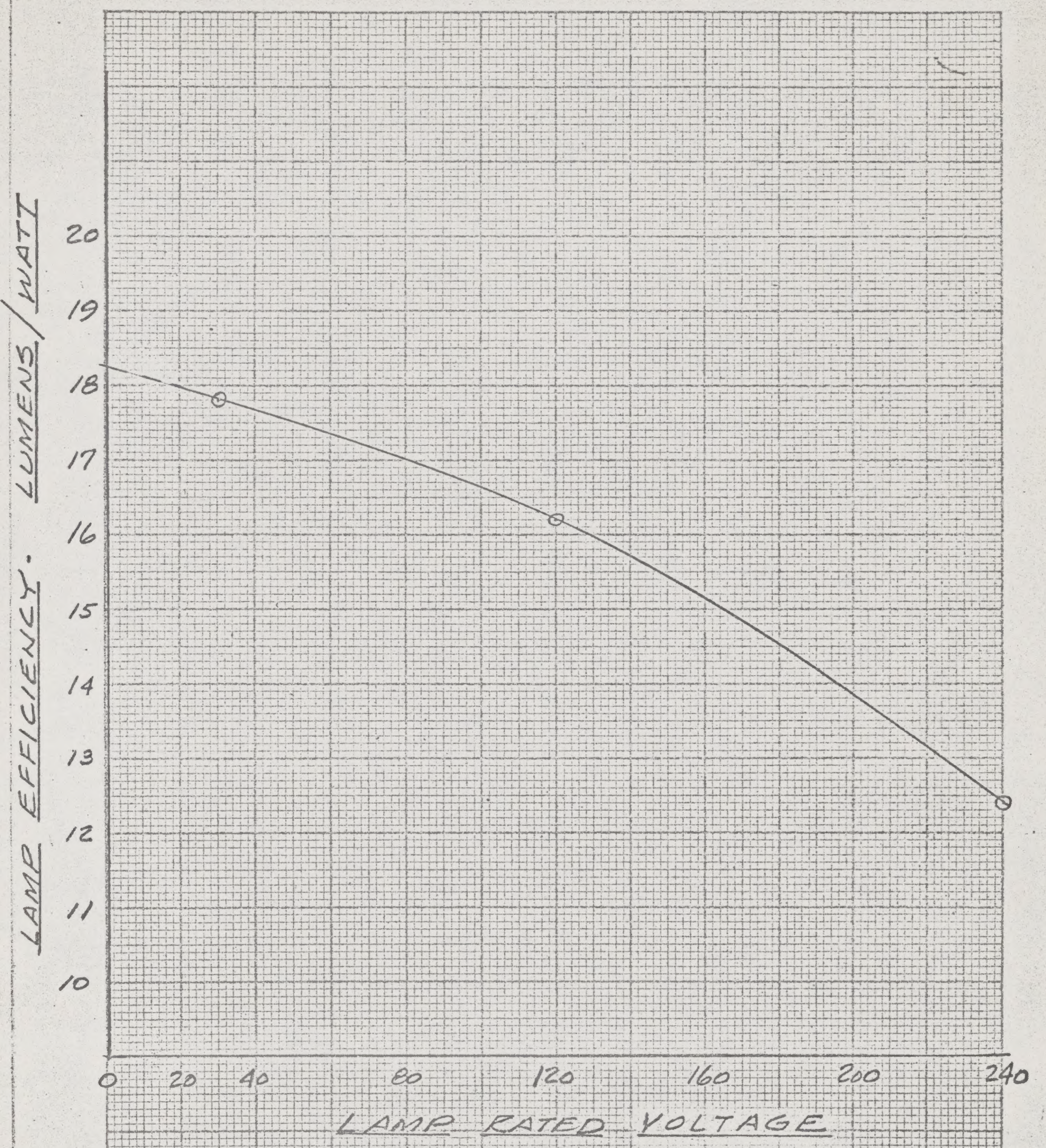

FIG. 3.

(2) IMPROVEMENT IN 100 WATT LAMP EFFICIENCY WITH REDUCTION IN DESIGN VOLTAGE.

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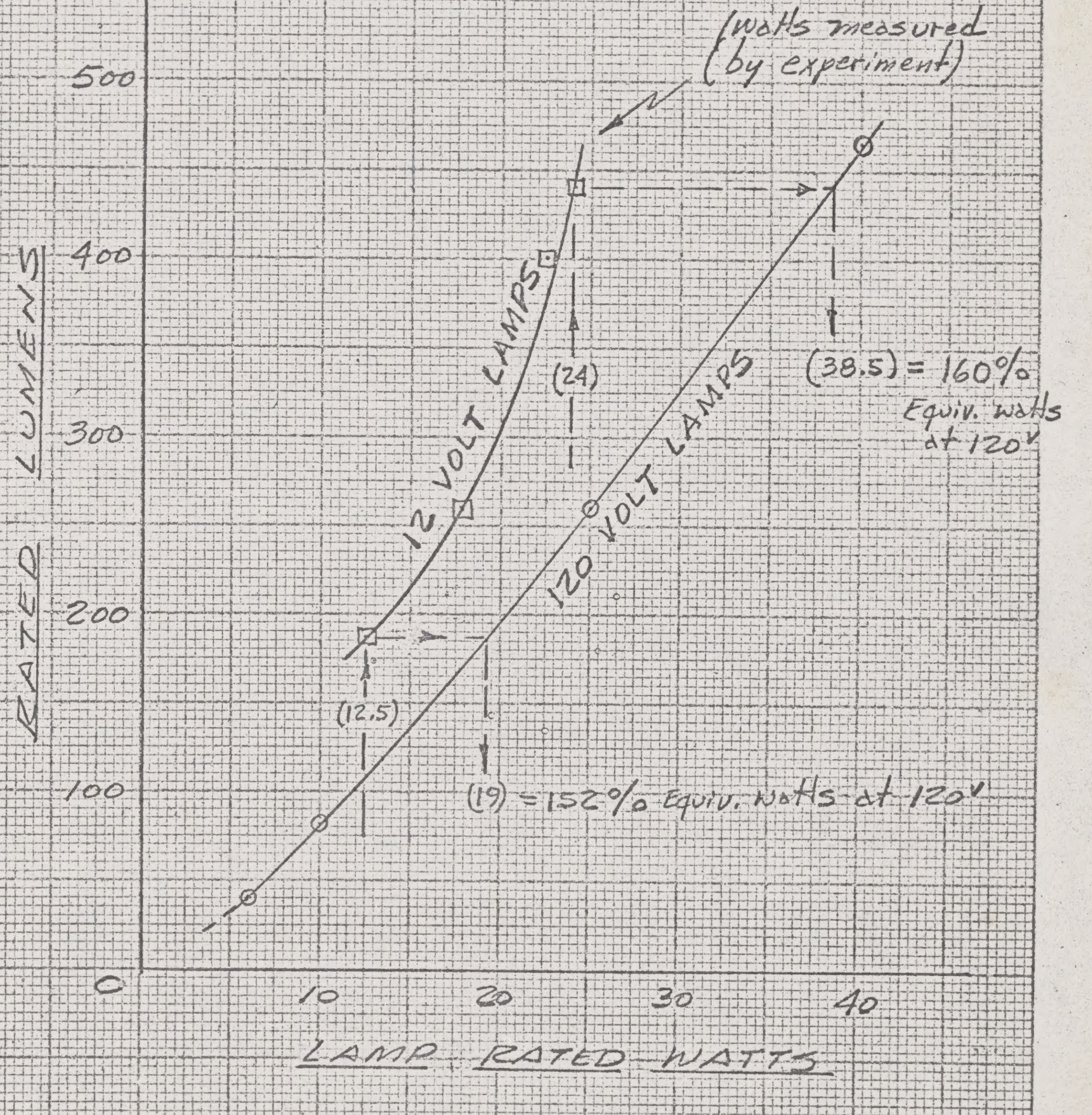

FIG. 4

(2) COMPARISON OF DIFFERENT
VOLTAGE LAMPS REQUIRED
WATTS FOR SAME LUMEN OUTPUT

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